

HIGHLY SIDEROPHILE ELEMENT AND ^{187}Re - ^{187}Os ISOTOPIC SYSTEMATICS OF UNGROUPED ACHONDRITE NORTHWEST AFRICA 6704 G. J. Archer¹, R. J. Walker¹, A. J. Irving², and Y. Amelin³. ¹Department of Geology, University of Maryland, College Park, MD 20742 (garcher@umd.edu). ²Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195. ³Research School of Earth Sciences, The Australian National University, Canberra ACT 0200, Australia.

Introduction: Early differentiation processes occurring on planetary bodies were likely complex, and could have differed considerably between bodies. Some differentiated achondrites have isotopic closure ages within only a few million years of the formation ages of calcium-aluminum-rich inclusions, considered to be the first solids to form in the Solar System. These achondrites may, therefore, provide insights into processes involved in early planetary differentiation, such as core formation, silicate mantle differentiation, initial formation of crust, and subsequent late accretion.

The highly siderophile elements (HSE), including Re, Os, Ir, Ru, Pt, and Pd are particularly useful for investigating early differentiation processes. Their initial abundances in the silicate mantles of differentiated bodies reflect the end stage of core-mantle partitioning of these elements. They may also be useful for assessing subsequent mantle processes, such as magma ocean crystallization, because of their diverse compatibilities in silicate systems [1]. Further, as late accretion returns HSE to the silicate portions of differentiated bodies, their abundances are useful for assessing the magnitude of late-stage planetary accretion [e.g., 2]. Finally, the ^{187}Re - ^{187}Os isotopic system ($^{187}\text{Re} \rightarrow ^{187}\text{Os} + \beta$; $\lambda = 1.67 \times 10^{-11} \text{a}^{-1}$) in early Solar System materials is useful for assessing whether HSE distribution reflects dominantly primary or secondary processes [3].

Investigating the distribution of HSE in various differentiated achondrites can provide a comprehensive assessment of early differentiation processes acting on different planetary bodies. Ungrouped achondrite NWA 6704, together with paired NWA 6693 and closely related NWA 10132, are meteorites with unique geochemical characteristics that are thought to come from a parent body unlike the sources of other known meteorites. NWA 6704 has an igneous cumulate texture and relatively ferroan silicates (olivine $\text{FeO}/\text{MnO} = 120$ to 140) [4]. It comprises olivine, chromite, orthopyroxene, sodic plagioclase, Cr-Spinel, and very Ni-rich metal (0.4% awaruite) [5]. The $\Delta^{17}\text{O}$ of NWA 6704 is similar to lodranites and acapulcoites [4], however its mineralogy and Cr isotopic composition [6] differ. A prior study reported a Pb-Pb age of 4563.75 ± 0.41 Ma [7].

Here we present a combined dataset of HSE abundances and ^{187}Re - ^{187}Os isotopic systematics for this meteorite, and consider the processes that may have

established the HSE characteristics and Re-Os isotopic systematics of these samples.

Methods: Metal separates, crushed silicate separates, and crushed bulk fragments of NWA 6704 were combined with two isotopic spikes, one enriched in ^{185}Re and ^{190}Os , the other enriched in ^{191}Ir , ^{99}Ru , ^{194}Pt , and ^{105}Pd . Samples, spikes, and ~ 5 mL 2:1 concentrated $\text{HNO}_3 + \text{HCl}$ were sealed within Pyrex Carius tubes and heated to 260°C for 72 hours [8]. Osmium was then removed via solvent extraction using CCl_4 and back extraction into HBr [9], and purified by microdistillation [10]. All other HSE were purified using anion exchange chromatography. Purified Os was analyzed by negative thermal ionization using either a *VG Sector 54* or a *Thermo-Fisher Triton* mass spectrometer. Rhenium, Ru, Pt, Ir, and Pd were analyzed using a *Nu Plasma* multi-collector-ICP-MS. Only the silicate fraction had significant blank corrections for Re (2.6%), Os (1.4%), Pt (1.5%), and Pd (3.9%). Blank correction uncertainties are reflected in reported uncertainties.

Results: Bulk samples of NWA 6704 have broadly chondritic HSE abundances, with $\sim 0.2x$ to $\sim 7x$ CI Os. The metal fraction has high HSE abundances, with $\sim 65x$ CI Os. By contrast, the silicate fraction has low HSE abundances, with $\sim 0.03x$ CI Os. All samples are characterized by only modestly fractionated HSE patterns, relative to chondrites (Fig. 1).

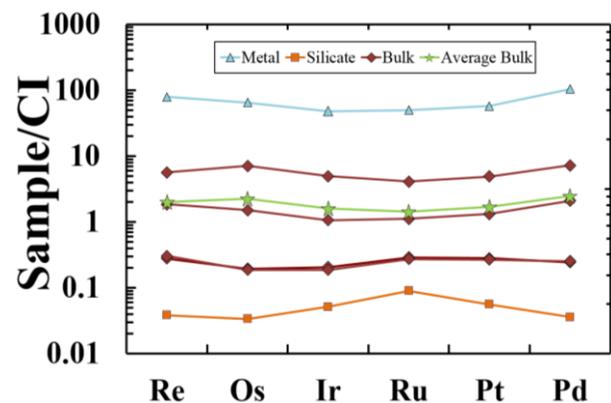


Figure 1. CI normalized [11] HSE abundances for bulk samples, and metal and silicate separates of NWA 6704. Uncertainties are smaller than symbols.

All NWA 6704 fractions, except for the silicate fraction, plot on or very near a ~ 4.57 Ga primordial reference isochron (Fig. 2), and have Δ_{Os} values < 5 (Δ_{Os} is the deviation in parts per 10,000 from a primor-

dial reference isochron [12]). The silicate fraction plots off the primordial isochron with a Δ_{Os} value of -23.9 ± 10.2 .

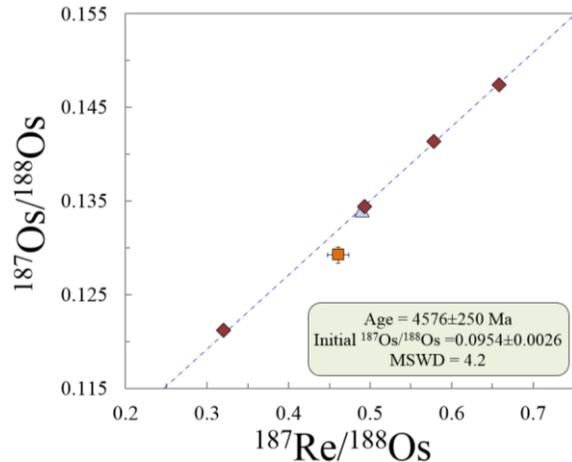


Figure 2. $^{187}\text{Re}/^{188}\text{Os}$ vs. $^{187}\text{Os}/^{188}\text{Os}$ for bulk samples, and metal and silicate separates. The silicate separate is not included in the regression. Symbols are the same as in Fig. 1. Unless shown, error bars are smaller than symbols.

Discussion: The ^{187}Re - ^{187}Os isotopic systematics of bulk samples and the metal separate are consistent with system closure since formation. The small but significant deviation of the silicate fraction from the 4.5 Ga isochron most likely indicates minor Re mobility during terrestrial alteration. It is unlikely that this process greatly affected HSE distributions within the meteorite, hence, observed HSE fractionations most likely reflect formational processes.

Following core formation, HSE abundances in the silicate portions of initially chondritic planetary bodies are likely highly depleted and fractionated, relative to bulk chondrites [e.g., 13]. The nearly chondritic HSE abundances of bulk fractions of NWA 6704 are too high and unfractionated to reflect core formation in the parent body. Thus, we conclude that the parent body of NWA 6704 had not undergone a global core formation event by the time this sample formed, and may have never undergone core formation.

Instead, the absolute and relative abundances of the HSE most likely reflect localized partial melting and fractional crystallization of silicate melt. Prior studies of other differentiated achondrites (e.g., GRA 06128-9; [14]) indicate that these processes were active in other planetary bodies early in Solar System history. Other aspects of this meteorite are also consistent with this interpretation. A study of a meteorite NWA 6693, paired with NWA 6704, argued that the subchondritic MgO/SiO_2 was consistent with derivation from an extracted partial melt [5]. However, the nearly chondritic relative HSE abundances of bulk fractions of NWA

6704 are inconsistent with extensive silicate fractionation. Consistent with the interpretations of [5], it is more likely that this sample crystallized from a melt that had undergone only minor fractionation, and that the subchondritic MgO/SiO_2 was characteristic of the primary magma.

There are small deviations in HSE abundances of NWA 6704 bulk and silicate fractions away from chondritic relative abundances. A prior study reported depletions in the abundances of S and chalcophile elements in the paired meteorite NWA 6693 [5]. The minor HSE fractionations of NWA 6704 bulk and silicate samples may, therefore, be the result of sulfide loss from a system in which metal acted as the primary HSE carrier, and sulfides acted as a minor carrier. If sulfide loss did occur, it only removed a small quantity of Fe-rich metal from the system.

Further, the spread in Re/Os among NWA 6704 bulk fractions (**Fig. 2**) may be the result of Re/Os fractionation during oxidation, as Re has the highest oxidation potential of the HSE. Prior studies [4] have reported high Ni content in NWA 6704 metal, consistent with formation under highly oxidizing conditions.

It is also possible that the melt from which this rock crystallized inefficiently assimilated exogenous material that was added shortly before or after crystallization, as a result of late-stage impacts on the parent body. The variation in absolute abundances of HSE in bulk fractions of NWA 6704 indicate that the major HSE carriers (Fe,Ni-rich metal grains) are heterogeneously distributed. The HSE-rich metal grains could represent material from a hypothetical impactor, and bulk fractions with higher HSE abundances received larger fractions of this exogenous material. However, there are currently no known meteorites with HSE characteristics similar to NWA 6704 metal grains, and this model is therefore difficult to test.

References: [1] Barnes S.-J. et al. (1985) *Chem. Geol.* **53**, 302-323 [2] Day J.M.D. et al. (2012) *Nat. Geosci.* **5**, 614-617 [3] Becker H. et al. (2001) *Geochim. Cosmochim. Acta* **65**, 3379-3390 [4] Irving A.J. et al. (2011) 74th *Metsoc* abstract #5231. [5] Warren P.H. et al. (2013) *Geochim. Cosmochim. Acta* **107**, 135-154. [6] Sanborn M.E. et al. (2013) 76th *Metsoc* abstract #5220. [7] Iizuka T. et al. (2013) 44th LPSC abstract #1841. [8] Shirey S.B. and Walker R.J. (1995) *Anal. Chem.* **67**, 2136-2141 [9] Cohen A.S. and Waters F.G. (1996) *Anal. Chim. Acta* **332**, 269-275 [10] Birck J.L. et al. (1997) *Geostand. Newsl.* **21**, 19-27. [11] Horan M.F. et al. (2003) *Chem. Geol.* **196**, 5-20. [12] Becker H. et al. (2001) *Geochim. Cosmochim. Acta* **65**, 3379-3390 [13] Capobianco et al. (1993) *J. Geophys. Res. - Planets* **98**, 5433-5443 [14] Day et al. (2009) *Nature* **457**, 179-182.